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12 March 2020

Version of attached file:

Accepted Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Rahman, M. Mojibar and Haque, Shahroz Mahean and Galib, Shams M. and Islam, M. Ashraful and Parvez, Md. Taskin and Hoque, Md. Nazmul and Wahab, M. Abdul and Egna, Hillary and Brown, Christopher (2020) 'Mud crab fishery in climate vulnerable coastal Bangladesh : an analysis towards sustainable development.', *Aquaculture international*, 28 (3). pp. 1243-1268.

Further information on publisher's website:

<https://doi.org/10.1007/s10499-020-00523-2>

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Mud crab fishery in climate vulnerable coastal Bangladesh: an analysis towards sustainable development

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ABSTRACT

Developing countries are far more vulnerable to climate change impacts than industrialized countries. Most of the world's poor live in South Asia where they have limited livelihood options that have become even narrower in recent years, indicating a need for alternative income-generating options. Mud crabs (*Scylla* spp.) are considered to have promising prospects in different parts of the world including Bangladesh, a well-known region for its vulnerability to climate change. At present this fishery has become a growing venture in coastal Bangladesh, primarily due to the potential of the export market and availability of

seed locally. This study included a calculation of the Human Development Index linked to mud crab fishery (HDIMCF) and a SWOT (strengths, weaknesses, opportunities, and threats) analysis to clarify the present status of and strategic directions for the mud crab fishery, for the first time. Results revealed an intermediate level of development of mud crab aquaculture, indicating potential alternative livelihood opportunities for vulnerable coastal communities. The SWOT analysis revealed that positive factors, both internal (strengths) and external (opportunities), predominate over negative factors (weaknesses and threats) and that the fishery can be an alternative livelihood option for vulnerable coastal communities. Despite noticeable diversification of the mud crab fishery, dependence on wild seedstock and possible over-exploitation in the wild appear to constrain sustainable development of the fishery. This study's findings suggest undertaking immediate wild crab stock assessment for determining current status of wild populations. Moreover, modification of the Government of Bangladesh's existing mud crab policy is needed to better meet growing demand and sustainability of the fishery. Recommendations of this study may be of help in guiding responsible integrated coastal fisheries management and policy.

Keywords: Mud crab aquaculture, *Scylla* spp., climate change, HDI, HDIMCF, SWOT, conservation, coastal Bangladesh, coastal management policy

1. INTRODUCTION

Coastal communities are particularly vulnerable to climate change impacts, especially those in developing countries (Hoegh-Guldberg and Bruno 2010; Chinowsky et al. 2011; Barbier 2015). About 38% of the world's population lives in coastal areas (UNEP, 2014) of which over three quarters (1.9 billion) are in developing countries (Barbier 2015) with relatively poorer capacity of mitigating climate change impacts (Chinowsky et al. 2011). South Asia, particularly known for its vulnerability to climate change, supports the largest poor rural populations of the world with the highest rate of infant mortality (40 million in South Asia) and malnourished children (35 million); Bangladesh ranked within top two countries on these lists (Barbier 2015). Livelihood options are limited and primarily depend on fishing, aquaculture, agriculture and manual work as daily labourers (Tobey and Torell 2006; Paul and Routray 2011). In recent times, livelihood options have become even narrower due to climate change impacts. For example, salt water intrusion has adversely affected the agricultural cropping and livestock in 105.6 million ha areas of coastal Bangladesh, reducing up to 92% of cropping areas in some locations (Chowdhury et al. 2011; Mahmuduzzaman et al. 2014; Alam et al. 2017; Hoque et al. 2018). Salinity intrusion in coastal areas has increased about 26% between 1973 and 2009 (Mahmuduzzaman et al. 2014; Alam et al. 2017). This impact exemplifies the need for alternate livelihood options for vulnerable communities, toward improved resilience and maintenance of socio-economic status.

The utilisation of mud crab has been commercially practiced for many years in different parts of the world including South and Southeast Asian countries (Overton and Macintosh, 1997). In recent times the global demand for commercial exploitation of mud crab fisheries and aquaculture has rapidly increased and is expected to continue to increase (Azra and Ikhwanuddin 2016; Hungria et al. 2017). In 2015, the world production of mud crabs was roughly 226,390 metric tons with a farm-gate value of US\$1.06 billion (FAO 2015). Currently four species of mud crabs, *Scylla serrata*, *S. olivacea*, *S. tranquebarica*, and *S. paramamosain* are considered economically valuable and common in aquaculture in different parts of the world (Keenan and Blackshaw 1999; Allan and Fielder 2003). The commercial market for crabs is driven by different forms of the product including live, chilled, frozen, and processed (Hungria et al. 2017).

In nature mud crabs are widely distributed in the Western Indo-Pacific (Keenan et al. 1998; Macintosh et al. 2002) and abundantly found in Bangladesh's southwest coastal waters including the Sundarbans mangrove forests and adjacent areas (Chandra et al. 2012). The coastal environment of Bangladesh can potentially be utilised for capture, culture, and trade of mud crabs (Islam et al. 2015; Hussain et al. 2018) especially *S. serrata* (Saha et al. 2000).

Crabs have been harvested from the Sundarbans and its surroundings for several decades for export and, as juveniles, to be reared in brackish water ponds with the aim of exporting them when they reach a suitable size. In Bangladesh, the export of crabs to international markets first started in 1977–1978. Since 1982 crab export has been solely based on harvest from the wild (Rahman et al. 2017). Farming mud crabs, primarily entailing fattening, has gained popularity since the mid-1990s (Azam et al. 1998), while other forms of crab culture (e.g., cage culture, pen culture and polyculture) started in 2000s (Khatun et al. 2009). Currently crabs are being produced in 27,010 ha of coastal ponds in Bangladesh (FRSS 2017).

The mud crab fishery can potentially offer a wide range of economic options to stakeholders, as a source of income, nutrition, and livelihoods for vulnerable people of coastal Bangladesh, a well-known region for its vulnerability to climate change (Molla et al. 2009; Rahman et al. 2017). Although crab farming is an economically promising activity, industry development is constrained by inadequate research focused both on the mud crab fishery and biology of species. Therefore, this fishery remains relatively undeveloped in coastal Bangladesh, and is in need of comprehensive planning and strategic decision-making toward its sustainable growth and development. Despite an earlier socio-economic study of the mud crab fishery to determine its contribution to coastal communities (Istiaq 2018), no such studies, to the best of our knowledge, have yet been carried out.

The SWOT analysis is a simple, flexible, and effective tool to inform the preliminary stages of decision making and as a precursor to long-term strategic planning in various disciplines (Johnson et al. 1989; Bartol and Martin 1998; Chermack and Kasshanna 2007) including marine and freshwater sciences (Stead 2005; Panigrahi and Mohanty 2012). The SWOT analysis can be broadly utilised in evaluating internal (strengths and weaknesses) and external (opportunities and threats) factors by gathering opinions from relevant key stakeholders of a particular sector (Coman and Ronen 2009; Helms and Nixon 2010). Such an examination of internal and external factors can assist in shaping the future of a sector of interest (Çelik et al. 2012) including aquaculture (Garza-Gil et al. 2009; Rimmer et al. 2013). In this study, the SWOT analysis can help identify the embedded and anticipated issues of the mud crab fishery of coastal Bangladesh, for the first time, that are likely to influence its sustainable development.

2. METHODS

2.1 Study sites

The study was carried out in three coastal districts: Satkhira, Khulna, and Bagerhat (21°43' to 22°57' N and 88°56' to 89°55' E) of southwest Bangladesh where the mud crab fishery is primarily based (Figure 1) and are also well-known areas for vulnerability to climate change impacts. Various activities of the mud crab fishery --including wild crab collection, crab fattening, grow-out culture, soft-shell crab production, processing, transportation and marketing—contribute to a harvest of more than 70% of the total mud crabs in the country (Istiak 2018).

2.2 Identification of stakeholders and socio-economic survey

The mud crab fishery stakeholders are those individuals or groups who depend on the fishery to fulfil their livelihoods or vice versa, on whom the fishery depends (Johnson and Scholes 1997). Different heterogeneous groups of fishery stakeholders (wild crab collectors, crab fatteners, *farias* [mid-level participants in the marketing channel who buy crabs from collectors/farmers], depot holders, suppliers, transporters, input suppliers, exporters, service providers etc.; Figure 2) in the study areas were identified by visiting in person.

Members of the two major groups of stakeholders – crab collectors (fishermen engaged in catching wild crabs; $N = 75$, 25 from each of the three districts) and crab farmers (who rear wild crab in coastal ponds for the purpose of crab fattening, grow-out, and soft-shell production; $N = 150$, 50 from each district) – were interviewed with a semi-structured survey to obtain information of their socio-economic profile and interaction with the mud crab fishery. In addition, 15 focus group discussions (FGDs), five in each sampling district, were also organised with mud crab stakeholders. We conducted outcross-check interviews with several key informants (KI) including three Fisheries Officers, five NGO personnel, and five fisheries researchers with relevant expertise. Socio-economic data were subjected to simple descriptive analysis.

2.3 Human Development Index linked to mud crab fishery (HDIMCF)

The Human Development Index (HDI) was developed to prioritise people and their capabilities for assessing the development of a country, and was not based on economic growth alone. In this study, we linked HDI to the mud crab fishery of the study area. To calculate HDIMCF, we used a slightly modified formula of Germain et al. (2015) to better suit our study due to the similarities in business venture and community concerned between studies. However, the HDI formula adopted by Germain et al. (2015), where three sub-indices (Economic Index, Schooling Index, and Health System Index) were considered, was originally a modification of the initial HDI formula proposed by the UNDP (2010). In our study, we replaced the Health System Index by the Life Expectancy Index of the original HDI

formula in order to obtain the HDIMCF value. This is because Germain et al. (2015) used 'health insurance' data for calculating the Health System Index, but none of our respondents had health insurance.

$$\text{HDIMCF} = 0.5 (\text{EI}) + 0.1 (\text{SI}) + 0.4 (\text{LEI})$$

Where EI = Economic Index, SI = Schooling Index, and LEI = Life Expectancy Index.

The EI carries more weight than the educational and health indices because quality education and health supports are not possible without sufficient financial resources (after Germain et al. 2015). The equations for calculating EI, based on the average, maximum, and minimum monthly income, and SI, based on average, maximum, and minimum schooling year, are available elsewhere (see Germain et al. 2015 for details). However, instead of incorporating estimated income data, as used by Germain et al. (2015), we used wild mud crab collectors' and crab farmers' actual monthly income generated from the crab fishery, obtained during socio-economic surveys. For LEI, the following equation was used: $(72 - 20) / (85 - 20)$ as the HDI measures life expectancy from 20 to 85 years and the mean life expectancy at birth in Bangladesh is 72 years. The HDIMCF was expressed within a range from 0 to 1 and classified as low (0.000 – 0.499), medium (0.500 – 0.799), and high (0.800 – 1.000) human development for the HDIMCF (Germain et al. 2015).

2.4 SWOT analysis

A comprehensive participatory workshop was organised in September 2017 for screening potential, prospects, status, and sustainability of the mud crab fishery (Chambers et al., 1989) with 34 participants belonging to various stakeholder groups. Informative presentations provided an overview of the mud crab fishery sector including primary data generated from field, followed by detailed discussion of nuances of the fishery. Subsequently, the participatory SWOT analysis was facilitated around clustered issues by group work, followed by classifying and consensus-building for the identification of specific strengths and weaknesses, as well as the identification of specific opportunities and threats of the sector (Nouri et al. 2008; Helms and Nixon 2010). During the SWOT analysis, representatives of all stakeholder groups were organized to maximize their chances of contribution toward a list of relevant economical, ecological, and societal issues of the mud crab fishery. The list will form a basis for further implementation of the study results (after Mollenhorst and de Boer 2004).

After the identification of internal and external factors, a prioritization process was done by evaluating their positive and negative contributions to the fishery. Internal factors include

strengths and weaknesses and were weighted on a scale ranging from 0.01 to 1.0 (least important to most important) such that the sum of these weights are equal to one (after Nouri et al. 2008; Ommani 2011). An individual rating, ranging between 1 and 4, was allocated to each of the factors where rate 1 represents severe weakness, 2 denotes common weakness, 3 shows common strength, and 4 represents vital strength. The score for each of the factors, determined by multiplying the weight by the rate, represents the importance of the corresponding factor. However, a total score of less than 2.5 for all the effective factors represents that weaknesses are more prevalent than strengths and a total score of more than 2.5 indicates that strengths dominate over weaknesses (Nouri et al. 2008). External factors, consisting of opportunities and threats, were also evaluated as mentioned earlier. The fishery is able to rely on its most important strengths towards well-being for the sector (Jurevicius 2013).

3. RESULTS AND DISCUSSION

3.1 Socio-economic conditions of mud crab collectors and farmers: Human Development Index linked to the mud crab fishery (HDIMCF) in southwest Bangladesh

The mean (\pm SD) age of crab collectors and farmers were 34.6 ± 9.1 (range: 16 – 59) years and 36.7 ± 9.7 (range: 24 – 56) years, respectively. Although a majority of crab collectors and farmers (~70 – 75%) were men, a considerable portion of the total respondents of both communities (~25% crab collectors and ~30% crab farmers) were women. This represents greater involvement of women in crab farming than in fisheries and aquaculture worldwide (~14%; FAO 2018) and in other forms of agriculture production in Bangladesh (3.85% in crop cultivation; Mamun-ur-Rashid et al. 2017). Most respondents were married (77–80%) with a small proportion that were single, widowed, or divorced (Table 1).

A majority of the crab collectors (78.7%) and crab farmers (64%) were Hindus followed by Muslims and Christians (Table 1) which is a common trend among fishing communities in Bangladesh (Islam et al., 2013). Crab collection or farming was not the only income generating activities of the respondents in the study area, as 65% of crab collectors and 58.7% of crab farmers had secondary occupations (Table 1). The land holding status of crab farmers was slightly greater than that of crab collectors, with about 80% of wild crab collectors owning 0–4000 m² of land and about 80% crab farmers owning 2000–6000 m² (Table 1). Similar findings were also noted when income was considered, in that crab farmers earned more than crab collectors. Several sources of finance were identified in the study areas but interest rates for loans were high, except for government banks, as reported by respondents.

The Economic Index (EI) of crab collectors was comparatively higher (0.58) than crab farmers (0.49) (Table 2) reflecting, for both collectors and farmers, a moderate income-level that affects HDIMCF and is scored as 'medium' by HDI standards (Germain et al. 2015). This state was also reflected by their income, land holding status, and standard of living (Table 1). The monthly income varied between low to moderate (8700–32000 BDT; ~85 BDT = 1 US\$ in 2020) levels for both crab collectors and farmers. Participants reported that about 70–100% of their income was generated from the mud crab fishery.

For Schooling Index (SI), scores for both crab collectors and farmers were classified as 'low' by the Human Development Index (Germain et al. 2015). Education level was higher among crab farmers as compared to crab collectors; 17% of crab collectors had no schooling background (Table 1). Poor education of the crab collectors was also reported earlier in Bangladesh (Molla et al. 2009) and reflects a similar situation all over the country. This is primarily the result of early engagement in an economic activity to assist the household economically. Despite having a desire to go to school or pursue higher education, as mentioned by all the respondents, it was not possible due to lack of financial support. However, respondents expressed their desire to send their children to school and to encourage them towards literacy. Eventual improvements in the literacy of farmers' and collectors' children can play a significant role in increasing the HDIMCF in the near future.

Life Expectancy Index values were found to be the same for both stakeholder groups because life expectancy at birth in Bangladesh was the same for both groups, at 72 years. The HDIMCF was similar for both crab collectors and crab farmers (Table 2). Respondents reported few serious health issues, as crab collectors (16%) and crab farmers (14%) did not suffer from any common diseases over the year whereas a majority of them (74.7% and 26% for crab collectors and farmers, respectively) suffered from gastritis (Table 1). Respiratory problems were more common among crab collectors (41.3%) than crab farmers (15.3%) and this could be attributed to the frequent fishing trips by the crab collectors to mangrove areas, often for several days, which exposed them to cold. Irregular meals during these fishing trips also make them susceptible to gastritis. However, treatments for their ailments were not optimal, as almost two-thirds of collectors and more than one-third of farmers reported that they received care from village doctors who had no formal medical training. Although a considerable number of respondents went to the Upazila Health Complex, these facilities are not especially well-equipped and proper health care is seldom received by the patients (Aldana et al. 2011; Toufique and Yunus 2013; M.M. Rahman, per. obs.).

3.2 Internal factors of the mud crab fishery

Evaluation of internal factors, focusing on both strengths and weaknesses of the mud crab fishery in southern Bangladesh, revealed that a range of factors can affect this fishery (Table 3). However, strengths dominated over weakness as the sum of score of all the factors was more than 2.5.

3.3.1 Strengths

Among strengths, high demand and price of mud crab scored the highest (0.36) followed by local availability (0.32), high tolerance to environment and diseases (0.28), and other factors (Table 3).

3.2.1.1 High export potential and price

In Bangladesh, the mud crab fishery is primarily an export-oriented venture (Chandra et al. 2012; Ferdoushi and Xiang-Guo 2013). High demand from international markets (Azam et al., 1998) continues to play a key role in developing the mud crab fishery in southern Bangladesh (Marichamy and Rajapackiam 1999; Rahman et al. 2017). The mud crabs are among the most popular and costly seafood in Southeast Asia (Pripanapong and Tongdee 1998) and elsewhere. Although all exportable forms (crab meats as a value-added product and frozen soft-shelled mud crab) are in high demand, live and soft-shell crabs command premium prices in export markets (Wickins and Lee 2002; Hungria et al., 2017). This helps people involved in the mud-crab value chain to obtain a high price, as recognised by all participants of this study.

3.2.1.2 Mud crabs are available locally in the wild

Though not yet extensively investigated, 28 crab species have been reported in coastal Bangladesh (Ahmed 2008) of which several species belonging to genera *Scylla*, *Portunus*, *Charybdis*, *Matuta*, *Varuna* and *Sartorina* are reported to be used for human consumption (Shafi and Quddus 1982). However, *Scylla serrata*, commonly available in the Sundarbans mangrove forests and associated coastal water bodies, is considered the most important in the country because of consistently high demand for this species in export markets. If properly managed, maximum sustainable yield could continuously be harvested from the wild to support the mud crab fishery in Bangladesh.

3.2.1.3 High tolerance

Because of high tolerance to environmental parameters and diseases, mud crab emerges among the fittest candidates for coastal aquaculture in Bangladesh. They are considered to be remarkably climate adapted and highly tolerant of salinity and temperature variation,

capable of surviving in salinities from 2–50 ppt and living in temperatures from 12–35°C (Bhuiyan and Islam 1981; Le Vay et al. 2001). Bangladesh is one of the most climatically vulnerable countries in the world (IPCC 2007) and its low lying coastal regions are extremely vulnerable to and affected by climate change impacts, e.g., hot summers, with increased salinity in soil and water; destructive storms and flooding (Rachel 2002). Regarding disease susceptibility, mud crabs have distinct advantages over widely cultured shrimp and prawn species (primarily *Penaeus monodon* and *Macrobrachium rosenbergii*) because shrimps are susceptible to infectious diseases including viruses in these environmental conditions, and if affected, complete mortality is common (Karim and Stellwagen 1998; Ali et al. 2016; M.M. Rahman and T. Pervez, per. obs.). Various conditions including contamination of shrimp, fraudulent inclusion of materials to increase weight, and presence of chemicals often result in export bans and complete loss of investment (Rahman et al. 2017). Eventually, many shrimp farmers are likely to shift to mud crab farming as crabs are currently less susceptible to disease and comparatively more resistant and adaptive to adverse aquatic conditions (Zafar et al. 2004; Islam et al. 2015).

3.2.1.4 Short cropping cycle

Mud crab culture, primarily crab fattening, has been practiced in coastal Bangladesh for about 25 years (Rahman et al. 2017). Year-round short cropping cycles of crab-fattening are common in all the study areas, adding flexibility and profit for farmers as compared with other aquaculture practices (e.g. finfish or shrimp culture) with longer cropping cycles (Ferdoushi and Xiang-Guo 2010). However, in crab fattening, 8 (in crab juvenile fattening, both sexes) to 18 (in fattening of unripe female crabs) crops can be harvested a year which is 5–15 times higher than other aquaculture species in Bangladesh. Growth rates of mud crab are relatively strong; crabs can reach a size of 300–400 g in 3 to 5 months (Johnston and Keenan 1999). It is also possible to culture mud crab with little or no capital, and without supplemental feed (Johnston and Keenan 1999; Rahman et al. 2017).

3.2.1.5 Diversified culture systems

Different culture technologies of mud crab are available, offering potential farmers flexibility in choosing among a variety of approaches. Culture strategies include fattening of mud crabs, as traditionally practiced in the study areas, along with grow-out farming (Azam et al. 1998; Rahman et al. 2017). In recent times, soft-shell crab production has been introduced and is gaining popularity in coastal Bangladesh; soft shell mud crabs command high prices and are believed to have strong potential for mass culture and business development

(Rahman et al. 2018). Apart from monoculture, polyculture is also possible together with tilapia and other finfish species in coastal ponds.

3.2.1.6 Alternative livelihood option

The marginalised coastal communities of Bangladesh are more vulnerable to climate change impacts due to their dependency on natural resources and lack of alternative livelihoods (Bauman 2002; Ellis and Allison 2004; ESPASA 2008). The mud crab fishery offers a potential source of financial security for maintaining livelihoods by providing a new source of income (Mirera and Mtile 2009; Rahman et al. 2017; Hussain et al. 2018), especially when other options (mostly shrimp farming) experience reduced production and when there are environmental and other challenges in coastal areas (Johnston and Keenan 1999; Chowdhury and Muniruzzaman 2003; Karthik et al. 2005; Islam and Bhuiyan 2016). Viral disease outbreaks in shrimp farms in 1995–96 led to reduced interest in coastal shrimp farming in Bangladesh (Karim and Stellwagen 1998) but fattening of wild-sourced mud crabs by some shrimp farmers showed hope as an alternate option for income. This fishery has recently emerged as an important component of coastal livelihoods offering employment and income opportunities (Salam et al. 2005; Rahman et al. 2017; Hussain et al. 2018) supporting more than 300,000 fishers, traders, exporters, and transporters (Islam et al. 2015). This range of positive economic prospects, in combination with inherent biological characteristics and favorable potential for human nutrition, suggest that improved coastal livelihoods are likely to result from the development of the mud crab fishery in Bangladesh. This integration of the commercial mud crab fishery into coastal ecosystem-based management (EBM) can potentially improve the resilience and adaptive capacity of poor and vulnerable fisher folks as they adapt to the impacts of climate change (Haq et al. 2015).

3.2.1.7 Simple culture technique

Mud crab culture technology is straightforward and requires a minimum of technical knowledge, skills, and investment when compared to other established aquaculture species (e.g. finfishes and tiger shrimp) in the study areas. Feeding is one of the major costs of any aquaculture operation including crab culture (Cholik 1999) though mud crabs can be fed with low-valued locally available freshwater and marine fishes, snails, poultry entrails, eels, and shrimp byproducts (e.g., heads) produced locally in culture systems. While at this time, respondents did not indicate that feeds were a significant negative, crustacean culture requires high protein feeds, which will be costly no matter the source. Presently the cost of crab feed is low because of the undervaluing of wild caught fish and other seafood byproducts. However, if crab culture becomes more intensified, problems with relying on wild

caught feed sources will magnify, and the biological requirements for high protein diets will drive feed costs to become a major portion of the farm operating budget. Locally available materials (mangrove twigs, straw-sheafs, coconut leaves, or shells of dead animals) can be supplied to the culture ponds for use by crabs as shelters, resulting in reduced cannibalism and increased survival and yield (Fielder et al. 1988; Chen 1990).

3.2.1.8 Exportable product ranking

Bangladesh exports a limited number of fishery products, of which frozen shrimp is the principal item. At present mud crab is ranked second among annual exports of fish and fish products after shrimp (FRSS 2017). Mud crab is therefore considered a very important exportable item with strong future potential because of its soaring demand and price in international markets (Rahman et al. 2017).

3.2.1.9 Increasing popularity

Popular interest in mud crab farming has been increasing rapidly in the study areas, primarily because of practical and perceived benefits over traditional aquaculture, especially shrimp culture (Johnston and Keenan 1999). Mud crab culture involves relatively lower environmental and economic risks because of the adaptability and high tolerance capabilities of crab (Zafor et al. 2004), coupled with high demand and price (Mahmud and Mamun 2012; Rahman et al. 2017). However, strong demand in international markets for Bangladeshi crabs has led to increased aquaculture and fisheries activities in coastal areas (Overton and Macintosh 1997; Rahman et al. 2017). This trend is reflected in the steadily increasing engagement of coastal people into the mud crab fishery. A six-fold increase has occurred within a half-decade period, from 50,000 people in 2009 to 300,000 people in 2015 (Molla et al. 2009; Islam et al. 2015).

3.2.2 Weaknesses

SWOT analysis revealed numerous limitations to the sustainable development of the crab fishery in Bangladesh. Participants acknowledged numerous issues working against the dynamic functioning of the growing mud crab fishery.

3.2.2.1 Dependency on wild stocks

The overwhelmingly most critical constraint on the mud crab fishery, wherever it is practiced, is the unavailability of hatchery raised crab seeds, typically leaving farmers dependent on wild-caught juveniles (Sathiadhas and Najmudeen 2004; Begum et al. 2009; Ferdoushi and Xiang-Guo 2013; Noorbaiduri and Ikhwanuddin 2015). Seedstock limitations restrict the

expansion of mud crab aquaculture and industry development globally (Shelley and Lovatelli 2011; Ikhwanuddin et al. 2012) as timely supply of seeds is practically impossible throughout the year. The fishery, as long as it remains dependent on wild crabs, is viewed as unsustainable for medium- or long- term development (Shelley 2008; Ikhwanuddin et al. 2012). The impact of such dependency is obvious in the mud crab export figures of Bangladesh, which was, despite high demand, not consistent over the period (Figure 3).

3.2.2.2 Unknown status of wild stock

Unfortunately, there are no population data of wild crabs in Bangladesh and thus, it is not possible to accurately determine the status of existing natural stocks. It has been speculated that the existing crab stock in the wild, primarily in the Sundarbans mangrove areas, is already at risk and possibly over-exploited (Chantarasri 1994; Azam et al. 1998; Kosuge 2001) and this may be influenced by collectors' poor educational status and lack of awareness of conservation concerns (Molla et al. 2009). Indiscriminate harvesting, harvesting freely during the breeding season, and destruction of natural habitats including breeding, feeding, and nursery grounds of crab have been reported more recently (Rahman et al. 2017). Unregulated and unmonitored harvests could potentially pose serious problems in the development of a sustainable crab fishery in the country.

3.2.2.3 Extensive culture system

Although different forms of crab cultures, viz. crab fattening, grow-out, soft-shell production, and polyculture were available in the study areas, small-scale traditional fattening of juvenile and unripe female crabs predominated. No standard crab culture manual or relevant literature is available in the country and existing culture methods do not ensure maximum production. Several problems including improper salinity, poor survival due to cannibalism, and water quality deterioration have been reported in crab farming (Ballio et al. 1981; Ferdousi and Xiang-Guo 2013), and as well by respondents of this study. No report of using improved technologies (e.g. use of suitable shelters to minimise cannibalism, cage and pen culture) was reported by respondents.

3.2.2.4 Poor post-harvest handling

Mud crabs have to go through a dozen hands and such post-harvest activities in Bangladesh have resulted in high mortality of live crabs during post-harvest handling. Lack of storage facilities was also common in the study areas, confirmed by the workshop participants, especially during transportation of live crabs from coastal areas to Dhaka (capital city of the country from which crabs are exported by air). For wild-captured crabs, survival rate is

affected by erratic handling, delayed landings, and poor transportation systems which negatively affect aquaculture output and national production (Zafor and Ahsan 2006). This loss during transportation is unusually high in Bangladesh, with reports of 14–20% mortality (Chandra et al. 2012) as compared to other crab producing countries (e.g. Philippines, with only 1% mortality; Gaillard 2010). This is due to heavy stress during the long transportation time in Bangladesh where crabs are transported using vertically elongated baskets resulting in increased weight on those crabs on the bottom of the basket, which contributes to mortality.

3.2.2.5 Lack of technical expertise

Training, and technical support and services are scarce and best management practices (BMPs) have not been standardized in the study areas. Moreover, there is no professional organization among crab farmers in the study areas, also reported earlier by Shelley (2013), making it difficult for the farmers to develop or share the knowledge and skills required to be an advanced farmer. Poor knowledge of crab farming of the respondents (e.g. stocking of heterogenic sizes of crabs, mixed-sex culture, escapement from ponds, avoidance of cannibalism) sometimes resulted in overall production loss (Baliao et al. 1981; Sulaeman and Hanafi 1993; Shelley 2008). The lack of technical training is thought to present a major obstacle to the development of crab aquaculture in Bangladesh (Ferdousi and Xiang-Guo 2013).

3.2.2.6 Lack of credit facilities

In the recent past, credit facilities were scarce in the study areas and it has been reported that the extremely poor coastal residents of Bangladesh including many actual and potential crab stakeholders (~20% of the total population) have no access to formal or informal credit (NRI Report 2003; Huq et al. 2015). However, at present, crab stakeholders, primarily crab collectors and farmers, have limited access to various financial instruments at high interest rates that can make them vulnerable to financial exploitation under difficult circumstances (e.g. sickness or death of an earning person in the family, and natural calamities) (Zafor and Ahsan 2006; Ferdousi and Xiang-Guo 2013).

3.2.2.7 Lack of standard marketing facilities

There is a prevailing sense of mistrust and misunderstanding at different levels within the mud crab marketing channel. An extensive and unstructured value chain, with virtually no government involvement disrupts the flow and fairness of mud crab trading in Bangladesh (Zafor and Ahsan 2006; Rahman et al. 2017). We found that crab grading criteria and price

varied from place to place and among depots in the study areas. Some farmers recognized unfair pricing as an issue, in part because farmers are excluded from the pricing process. Price fluctuation by unfair means by the actors in the middle and insufficient market information (e.g. up-to-date supply and demand data regarding both domestic and international markets) were reported by the respondents. These problems have also been recognised in other studies (e.g. Zafor and Ahsan 2006; Ferdousi and Xiang-Guo 2013; Rahman et al. 2017).

3.2.2.8 Limited domestic consumption

Traders who participated in this study mentioned that the mud crab business is solely export-oriented, with practically no domestic market, leaving them at the mercy of prices set by importers. The near absence of domestic demand allows little outlet for inferior crabs in local markets (Pollnac and Weeks 1992). In Bangladesh, social and religious restrictions on crab consumption, primarily among Muslims, have added to the undeveloped status of domestic markets (Ferdoushi et al. 2010), which is similar to the low local demand for shrimp.

3.2.2.9 Inadequate development commitment

There is negligible involvement of government and non-government organizations in the mud crab fishery in Bangladesh, which has hindered the development of this sector (Zafar and Ahsan 2006; Ferdoushi et al. 2010; Shelley 2013). The absence of appropriate policies and coordination measures among government agencies and other institutions is also perceived as a barrier to the development of the mud crab fishery. Conversely, involvement of a range of authorities (several ministries and government departments) has made the crab business a complex one (Istiak 2018) influencing some stakeholders to follow illegal practices.

3.2.2.10 Lack of information

Adequate data on mud crab culture, capture, production, and export are not available in the country. Although estimates of total export amount and value have been published for the past few years by the Department of Fisheries (FRSS 2017), it is believed that the actual figures are higher (Rahman et al. 2017). A reliable, detailed inventory of the mud crab fishery is essential in order to develop a proper strategic plan for this fishery. However, insufficient baseline data regarding any issue is quite common in Bangladesh (e.g. Chaki et al. 2014), and is sometimes extrapolated from data from neighbouring countries (e.g. India; Panigrahi and Mohanty 2012).

3.3 External factors of mud crab fishery

Similar to internal factors, external factors also involved a wide range of items including 11 opportunities and four threats (Table 4). Again, like internal factors, SWOT analysis showed that the opportunities dominated over the threats involved in the mud crab fishery in southern Bangladesh.

3.3.1 Opportunities

3.3.1.1 Availability of suitable water bodies for crab culture

Almost all the coastal ponds, locally known as *gher*, of Bangladesh are suitable for crab farming, reflecting the high potential for extension of this technology. There are 272,717 ha of coastal ponds currently being used for shrimp culture (FRSS 2017), which also have potential for mud crab culture. However, Salam et al. (2003) identified, based on GIS models, a total of 228,111 ha of suitable land; 552,897 ha of moderately suitable land; 30,072 ha of marginally suitable land, and 195 ha of unsuitable land for crab aquaculture in the coastal areas of Bangladesh. In addition, selected zones in the Sundarbans mangrove and inshore areas could also be considered for cage and pen culture of mud crabs, which are common practices in other countries involved in mud crab culture (e.g. David 2009).

3.3.1.2 Successful hatchery technology will substantially boost the fishery

Limitation in seed supply is a common problem in crab farming, leaving the supply of juveniles entirely dependent on wild sources (e.g. Fortes 1999; Noorbaiduri et al. 2014; Hungria et al. 2017). Success in hatchery seed production could result in a boom in the mud crab fishery in Bangladesh as has happened for the mitten crab industry in China (Rosenberry 2012). Despite inconsistent production of mud crab seed due to unpredictability in reproductive performance (Ghazali et al. 2017), efforts have been undertaken to produce seeds in captivity in several countries including Indonesia (Cholik 1999) and Malaysia (Noorbaiduri et al. 2014) with considerable success in some cases (e.g. in India; Anand and Soundarapandian 2011). Unfortunately, despite good potential for hatchery establishment (Salam and Ross 2000) the few initiatives undertaken in Bangladesh have met with limited or no success so far. However, hatchery improvements could help to protect natural stocks from being over-exploited (Ferdoushi and Xiang-Guo 2013; Quinitio 2015), and could offset some demand on wild seeds (Marichamy and Rajapackiam 2001).

3.3.1.3 Access to modern post-harvest facilities will reduce mortality and production loss

Rough handling and stress during the long transportation of mud crabs to market contribute to increased mortality (Liong 1991). Moreover, the absence of storage facilities results in a loss of overall production as crabs transported and stored under suboptimal circumstances

(e.g. political unrest or transportation delays) was commonly reported by the participants of this study. Thus, by promoting post-harvest facilities, especially storage and an effective cold chain, such losses can be reduced to a great extent.

3.3.1.4 Enterprise and industrial development

The mud crab fishery is an important feature of coastal fisheries in tropical and subtropical Asia (Le Vay 2001), including Bangladesh (Ferdoushi and Xiang-Guo 2010). Like shrimp, the most common aquaculture species in the southern Bangladesh, a separate industry could be developed if it receives proper attention from the appropriate bodies (e.g. government organisations) because mud crab offers a higher profit margin than other coastal aquaculture species including shrimp (Johnston and Keenan 1999; Sathiadhas and Najmudeen 2004). However, at present few crab depots have been established in recent times in different areas of southern Bangladesh. Substantially more depots are needed with more facilities.

3.3.1.5 Appropriate policies and initiatives can help the fishery become more economically functional

Currently there is no proper policy to guide the mud crab fishery in the country (Istiaq 2018). As the crab fishery is primarily an export-oriented business in Bangladesh, a policy, the 'Bangladesh Mud Crab Export Policy 1998', was introduced by the Bangladesh government to regulate export of crabs which is often blamed as a 'barrier' by the stakeholders for restricting the development of the crab fishery (Mahmud 2017). Per the same policy, wild crabs are only allowed to be collected using 'line hooks', but this practice is not recommended because it can injure crabs and damage burrows (Kasprzyk and Rajaonson 2013) resulting in high mortality and destruction of habitats. However, by formulating an appropriate policy, it is possible to make this sector more functional in order to support a wide range of stakeholders more efficiently and contribute more to national trade.

3.3.1.6 Potential coastal farmers

Fish farmers in the study areas have shown a positive response toward mud crab farming. This technology can be particularly important for the landless poor or those who have no private water access because they can rear crabs in cages in open waters, although this involves risk of poaching. Moreover, many shrimp farmers were also interested in shifting to crab farming due to adverse socio-economic and environmental issues associated with shrimp farming (Paul and Vogl 2011; Akber et al. 2018).

3.3.1.7 Improved technology and best management practices

Apart from traditional crab farming practices (e.g. fattening and grow-out) possibilities for increasing income through intensification include ripe female production and practicing crab fattening in cages (Overton and Macintosh 1997). Crab farming can also be integrated with forestry, rice culture, horticulture, and polyculture with fish, which are ineffective with shrimp farming (Chandrasekaran and Perumal 1993).

3.3.1.8 Potential for value addition and product promotion

The international market for value-added crab products (e.g., crab meat and frozen soft-shelled mud crab) has been growing over last two decades (Wickins and Lee 2002; Hungria et al. 2017). This is recognized for having good future potential for expansion.

3.3.1.9 Awareness building and law enforcement can support fishery sustainability

Proper implementation of fishery laws and regulations and mass awareness building programmes could be of particular help to save wild crab stock from the fishermen involved in indiscriminate catching. The level of awareness of the crab collectors, farmers, and traders was found to be poor with no knowledge of existing fisheries rules and regulations, both for crabs and other aquatic organisms. Although it is not permissible to export wild crabs, this practice was reportedly common in the study areas in which wild crabs were mislabelled and sold to local depots as farm-reared crabs. Moreover, fishing for crabs over restricted periods (breeding season, from January to February) in the Sundarbans mangrove is also regularly ignored by collectors.

3.3.1.10 Potential export markets

Currently the export markets for crabs from Bangladesh are limited. Of these, China is the main importing country, importing about 90% of the total from Bangladesh; other importing countries include Hong Kong, Taiwan, Singapore, Malaysia, Thailand, and Japan (Ali et al. 2004; Chandra et al. 2012; Rahman et al. 2017). However, there is a largely unexploited demand for value-added crab products worldwide including in Europe and North American countries (Fortes 1999; Hungria et al. 2017) and these are recognized as potential export markets for Bangladesh's mud crab fishery.

3.3.1.11 Promulgation of domestic consumption

Despite being an almost entirely export-oriented business, mud crab has little demand in local markets for the purpose of consumption by vulnerable and poor people including non-Muslims of the study areas. Some people buy crabs unsuitable for export (e.g. damaged, undersized, moribund etc.) at a low price. However, crabs are an excellent source of protein

and its meat contains essential amino acids, unsaturated fatty acids, minerals, and other micronutrients (Chen 1990; Gokoolu and Yerlikaya 2003). The perceived protein quality of crab meat is considered more favourable than other animal source foods (Derosier 1963; Zaitsev et al. 1969) and could be a source of protein for the poor rural population, with the caveat that crabs may still be too expensive as a reliable protein source, given tradeoffs when selling crabs and the availability of less expensive proteins such as legumes or fish. A small portion of the harvested crabs are being sold and served to customers at the restaurants of Cox's Bazar and St. Martin's Island. It is expected that this practice will expand to other areas, especially different tourist attractions in the future.

3.3.2 Threats

Few critical issues were identified during SWOT analysis that could hinder or threaten the promising mud crab fishery in Bangladesh.

3.3.2.1 Exports solely based on harvesting of wild stocks

Sustained efforts have reportedly improved crab seed production in some cases (Kumar 2015) and this would be the key to growing a sustainable mud crab industry globally (Salam and Ross 2000). Unfortunately, no success has been reported in Bangladesh so far and this fishery, to date, is totally dependent on wild-caught crabs. A continuous and sustainable supply of mud crab cannot be reliable in this way, which will impose limits on the expansion of the fishery in Bangladesh like many other countries of the world (Marichamy and Rajapackiam 2001; Shelley and Lovatelli 2011; Ikhwanuddin et al. 2012).

3.3.2.2 Excessive and indiscriminate harvesting of wild population

In Bangladesh, mud crabs were primarily caught from the Sundarbans mangrove areas. It has been reported that the fisheries resources, including crab populations, have already been over-fished in these areas (Chantarasri 1994), like other countries of Southeast Asia (Shelley 2008, Johnston et al. 2011) resulting in severe impacts on the genetic diversity of the crab population (Ahmed 1992; Acharya and Kamal 1994). Moreover, depletion of wild mud crab stock may lead to ecosystem imbalances resulting in ecological deterioration of water and soil, along with loss of biodiversity in the Sundarbans mangrove forests and other areas experiencing high fishing pressure.

3.3.2.3 Uncertain market in some cases

Although the demand for mud crabs is high, market price fluctuates commonly in Bangladesh, which sometimes can lead to dissatisfaction of the crab farmers. In addition, a

long marketing chain of mud crabs, with a high number of people in the middle, results in a higher product price that can lead to a collapse of this fishery because other exporting countries may offer the same product at competitively lower prices. Unexpected political events are also common in Bangladesh, and this can hamper any business especially marketing of perishable seafood products including crabs.

3.3.2.4 Disease outbreak

The history of the shrimp industry has shown that intensively cultured crustaceans can be vulnerable to disease outbreaks, as experienced in Bangladesh and elsewhere (Genodepa 1999; Johnston and Keenan 1999; Paul and Vogl, 2011). Potential impacts of infectious pathogens on intensive mud crab farming are not well established, although this could be particularly challenging during larval rearing in hatcheries (Cholik 1999).

4. CONCLUSIONS AND RECOMMENDATIONS

Outcomes of this SWOT analysis can contribute to the sustainable development of the mud crab fishery in Bangladesh. Both the positive internal and external factors (strengths and opportunities) showed dominance over negatives (weaknesses and threats), suggesting good potential for the rapid growth of this fishery in the country. The sector has clearly identifiable risks and limitations that can be minimised through proper monitoring and critical planning.

Studies are needed to determine the status of existing wild mud crab populations, especially in the Sundarbans mangrove areas, in order to formulate an appropriate management strategy to support the growing crab fishery while maintaining sustainable wild stock. This could be done by simple techniques (e.g. using baited traps; Kosuge 2001). Breeding and nursery grounds and possibly protected areas also need to be identified. Unfortunately, no comprehensive effort has been taken in Bangladesh so far except for few older localized studies (e.g. Chantarasri 1994; Hoq 2007) speculating possible over-exploitation of the wild crab population. However, reliable data on population dynamics need to be obtained and without this an effective strategy for the crab fishery, currently dependant on wild-sources, cannot be formulated. If data reveal that the wild crab population is at risk, efforts like habitat restoration and stock enhancement can be considered to mitigate the impacts of overfishing (Le Vay 2001; Walton et al. 2006).

Indiscriminate harvesting of wild crabs is common and this may be due to the limitations of existing management policy, which is inadequate to ensure effective conservation of mud

crab in nature. Even though the Bangladesh crab export policy forbids wild crabs to be exported, violation of this rule is often reported (e.g. Istiak 2018). Crab collectors are known to sell wild crabs directly to depot owners, from which they find their way to the export markets. The government should institute updated policies to regulate every step of the mud crab export chain effectively, as well as regulating capture from the wild. Despite having a fishing ban over the breeding season, illegal crab harvesting during this season was also reportedly common in the study areas. Strict monitoring by regulatory bodies and awareness programmes for crab collectors and local residences should be instituted. Modification of the existing mud crab export policy is also needed to meet crab fishery and conservation needs, rather than solely for export.

The mud crab fishery should be supported by government and non-government organisations through the development of a sustainable management strategy, offering extension services, training, and financial support for stakeholders. To address the scarcity of crab seed and to ensure its timely supply to the farmers, larviculture of crabs, as a supplementary method, could be considered (Chong 1995). Initiatives should also be taken to produce hatchery raised crab seeds commercially through induced breeding and larval rearing. This can reduce the dependency on wild crab seeds and be helpful for maintaining biodiversity in the wild. Currently there is a lack of expertise within the country and thus, foreign consultants of appropriate background could be hired to assemble a team involving national participants to address this issue. Loans at low interest rates need to be ensured for stakeholder groups, especially for the crab collectors and farmers.

The existing crab marketing systems require improvement. Initiatives could include introduction of processing and storage facilities at depots and elsewhere, standard grading systems and prices, and improved transportation facilities (e.g. mechanised vehicles, cold chain infrastructure, and appropriate carrying baskets) to improve the quality of products and also to shorten the marketing channel thereby promoting vertically integrated value chains. In addition, improved post-harvest systems and infrastructure can minimize deterioration under unexpected circumstances (e.g. political unrest) when transportation is not possible or difficult. Simple upgrades from baskets to crates could be an effective improvement during the transportation of live crabs, perhaps reducing losses by more than 60% (Kasprzyk and Rajaonson 2013).

Currently only one species of crab, *S. serrata*, is considered to have strong potential for aquaculture in Bangladesh. However, the merits of other crab species should also be evaluated. Crab farmers need to be trained about best management practices so that they can maintain a healthy culture environment, minimise loss of production through cannibalism

and disease outbreak, and optimize their culture systems. The mud crab fishery can generate substantial employment in different farming systems, including marketing, transportation, and other associated businesses directly and indirectly; however, sustainable practices should be strongly encouraged (Roy et al. 2013).

The poverty and poor education of crab collectors and farmers, along with religious and other relevant social concerns should be addressed in order to promote this sector. Promotional and educational activities (e.g. advertisement on mass media) could be considered with a view to expanding crab markets locally.

In summary, support of promising opportunities in mud crab must be coupled with the mitigation of threats through careful planning and regulation. The unusually strong potential of the mud crab sector as elaborated in the SWOT analysis suggests that the resolution of hatchery constraints united with a carefully conceived plan of development may contribute to the realisation of substantial trade and livelihood benefits from the mud crab fishery. A carefully conceived approach of this sort can enhance alternative livelihood options for climate-change vulnerable coastal communities. However, any strategic plan for the crab fishery, now based on wild crabs, must take into consideration the conservation of natural crab populations.

Acknowledgments

The research was supported by the former AquaFish Innovation Lab funded in part by the US Agency for International Development (USAID EPP-A-00-06-0012-00) and by participating institutions, particularly Bangladesh Agricultural University, North Carolina State University, Shushilon NGO, and Oregon State University. The AquaFish IL accession number is 1465. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the AquaFish Innovation Lab or USAID.

Conflict of Interest:

The authors declare that they have no conflict of interest.

Ethical statement

This article does not contain primary research involving animals or human subjects.

REFERENCES

Acharya G, Kamal D (1994) Fisheries, in: Hussain, Z., Acharya, G. (Eds.), *Mangroves of the Sundarbans in Bangladesh*. IUCN, Bangkok, Thailand, 2:101–114.

720 Ahmed ATA (2008) Marine Resources of Bangladesh. In: Ahmed, ZU, Begum ZNT, Hassan
 721 MA, Khondker M, Kabir SMH, Ahmad M, Ahmed ATA, Rahman AKA, Haque EU
 722 (Eds) Encyclopedia of Flora and Fauna of Bangladesh, Vol. 1 (Bangladesh Profile).
 723 Asiatic Society of Bangladesh, Dhaka.

724 Ahmed MK (1992) Mud crab - a potential aqua-resource of Bangladesh, in: Angell, C.A.
 725 (Eds.), Report of the Seminar on the Mud Crab Culture and Trade, 5–8 November
 726 1991, SuratThani, Thailand, pp. 95–102.

727 Akber MA, Islam MA, Ahmed M, Rahman MM, Rezaur M (2017) Changes of shrimp farming
 728 in southwest coastal Bangladesh. *Aquacult Int* 25:1883–1899.
 729 <https://doi.org/10.1007/s10499-017-0159-5>

730 Alam MZ, Carpenter-Boggs L, Mitra S, Haque MM, Halsey J, Rokonzaman M, Saha B,
 731 Moniruzzaman M (2017) Effect of salinity intrusion on food crops, livestock, and fish
 732 species at Kalapara coastal belt in Bangladesh. *J. Food Qual* 2017:2045157.
 733 <https://doi.org/10.1155/2017/2045157>

734 Aldana JM, Piechulek H, Al-Sabir A (2001) Client satisfaction and quality of health care in
 735 rural Bangladesh. *Bull. World Health Organ.* 79:512–517.

736 Ali H, Rico A, Murshed-e-Jahan K, Belton B (2016) An assessment of chemical and
 737 biological product use in aquaculture in Bangladesh. *Aquaculture* 454: 199–209.
 738 <http://dx.doi.org/10.1016/j.aquaculture.2015.12.025>

739 Ali MY, Kamal D, Hossain SMM, Azam MA, Sabbir W, Murshida A, Ahmed B, Azam K
 740 (2004) Biological studies of the mud crab, *Scylla serrata* (Forsk.) of the Sundarbans
 741 mangrove forest ecosystem in Khulna region of Bangladesh. *Pakistan J Biol Sci*
 742 7:1981–1987. <http://dx.doi.org/10.3923/pjbs.2004.1981.1987>

743 Allan G, Fielder D (2003) Mud crab aquaculture in Australia and Southeast Asia.
 744 Proceedings of the ACIAR Crab Aquaculture Scoping Study and Workshop, pp. 57–
 745 61.

746 Anand T, Soundarapandian P (2011) Sea ranching of commercially important blue
 747 swimming crab *Portunus pelagicus* (Linnaeus, 1758) in Parangipettai Coast. *Int J Sci*
 748 *Nat* 2:215–219.

749 Azam K, Kamal D, Mostofa M (1998) Status and potential of mud crab (*Scylla serrata*) in
 750 Bangladesh. In: Rahman MA, Shah MS, Murtaza MG, Matin MA (Eds.), Integrated
 751 Management of Ganges Floodplains and Sundarbans Ecosystem. Khulna University,
 752 Bangladesh.

753 Azra MN, Ikhwanuddin M (2016) A review of maturation diets for mud crab genus *Scylla*
754 broodstock: present research, problems and future perspective. Saudi J Biol Sci
755 23:257–267. <https://doi.org/10.1016/j.sjbs.2015.03.011>

756 Baliao DD, Rodriguez EM, Gerochi DD (1981) Culture of the mud crab *Scylla serrata*
757 (Forsk.) at different stocking densities in brackish water ponds. SEAFDEC
758 Aquaculture Department Quarterly Research Report, 5, 10–14.

759 Barbier EB (2015) Climate change impacts on rural poverty in low-elevation coastal zones
760 (English). Policy Research working paper; No. WPS 7475. World Bank Group,
761 Washington DC.

762 Bartol KM, Martin DC (1998) Management, third edition. Irwin/McGraw Hill Boston, MA.

763 Bauman P (2002) Improving access to natural resources for the rural poor. A critical analysis
764 of centre concepts and emerging trends from a sustainable livelihoods perspective.
765 Food and Agricultural organization of the United Nations, Livelihood support
766 programme. LSP Working Paper 1.

767 Begum M, Shah MMR, Mamun AA, Alam MJ (2009) Comparative study of mud crab (*Scylla*
768 *serrata*) fattening practices between two different systems in Bangladesh. J
769 Bangladesh Agril Univ 7:151–156.

770 Bhuyian AL, Islam MJ (1981) Tolerance and distribution of *Scylla serrata* in response to
771 salinity of Karnafuly River estuary, Bangladesh. Bangladesh J Agriculture 6:7–15.

772 Çelik A, Metin I, Çelik M (2012) Taking a photo of Turkish fishery sector: a SWOT analysis.
773 Procedia Soc Behav Sci 58:1515–1524.
774 <https://doi.org/10.1016/j.sbspro.2012.09.1138>

775 Chaki N, Jahan S, Fahad MFH, Galib SM, Mohsin ABM (2014) Environment and fish fauna
776 of the Atrai River: global and local conservation perspective. J Fish 2:163–172.
777 <http://dx.doi.org/10.17017/jfish.v2i3.2014.46>

778 Chambers R, Pacey A, Thrupp LA (1989) Farmer first: farmer innovation and agriculture
779 research. Intermediate Technology Publications, London.

780 Chandra KJ, Paul AK, Das DR (2012) A survey on the production and marketing of mud
781 crab, *Scylla serrata* (Forsk., 1755) in the south-west part of Bangladesh. Int Res J
782 Appli Life Sci 1:44–55.

783 Chandrasekaran VS, Perumal P (1993) The mud crab, *Scylla serrata*, a species for culture
784 and export. Seafood Export Journal 25:15–19.

785 Chantarasri S (1994) Fisheries resources management for the Sundarbans reserved forest,
786 in: Integrated Resources Development of the Sundarbans Reserved Forest,
787 Bangladesh, FAO/UNDP (BGD/84/656)-4, Draft Final Report. pp. 1–4.

788 Chen LC (1990) Mud crab culture. Aquaculture in Taiwan. Fishing News Books, Blackwell
789 Scientific Publications Ltd., London.

790 Chermack TJ, Kasshanna BK (2007) The Use and Misuse of SWOT Analysis and
791 Implications for HRD Professionals. Hum Resource Dev Int 4:383–399.
792 <https://doi.org/10.1080/13678860701718760>

793 Chinowsky P, Hayles C, Schweikert A, Strzepek N, Strzepek K, Schlosser CA (2011)
794 Climate change: comparative impact on developing and developed countries. Eng
795 Proj Organ J 1:67–80. <https://doi.org/10.1080/21573727.2010.549608>

796 Cholik F (1999) Review of mud crab culture research in Indonesia. In: Keenan CP,
797 Blackshaw A (Eds.), Mud crab aquaculture and biology, Proceedings of the ACIAR,
798 Australia, 78:14–20.

799 Chong LP (1995) Crab culture-present status, future prospects. Fishing Chimes 15:39–43.

800 Chowdhury MA, Khairun Y, Salequzzaman M, Rahman MM (2011) Effect of combined
801 shrimp and rice farming on water and soil quality in Bangladesh. Aquacult Int
802 19:1193–1206. <https://doi.org/10.1007/s10499-011-9433-0>

803 Chowdhury MBR, Muniruzzaman M (2003) Shrimp disease and its consequences on the
804 coastal shrimp farming in Bangladesh. In: Wahab MA (Ed.) Environmental and socio-
805 economic impacts of shrimp farming in Bangladesh. Technical proceeding, BAU-
806 NORAD Workshop, Dhaka, Bangladesh, pp. 39–48.

807 Coman A, Ronen B (2009) Focused SWOT: diagnosing critical strengths and weaknesses.
808 Int J Prod Res 47:5677–5689.

809 David MHO (2009) Mud crab (*Scylla serrata*) culture: understanding the technology in a
810 silvofisheries perspective. WIO J Mar Sci 8:127–137.

811 Derosier NW (1963) The technology of food preservation. The Avi Publishing Company Inc.,
812 USA, 20 pp.

813 Ellis F, Allison E (2004) Livelihood diversification and natural resource access. Food and
814 Agricultural organization of the United Nations, Livelihood support programme. LSP
815 Working Paper 9.

816 ESPASSA (2008) Ecosystem services and poverty alleviation study in South Asia. A
817 situation analysis for India and the Hindu Kush Himalayan region. The Energy and
818 Resource Institute, New Delhi, India.

819 FAO (2015) The state of world fisheries and aquaculture 2015. Food and Agriculture
820 Organization of the United Nations, Rome.

821 FAO (2018) The state of world fisheries and aquaculture 2018. Food and Agriculture
822 Organization of the United Nations, Rome.

823 Ferdoushi Z, Xiang-Guo Z (2010) Role of women in mud crab (*Scylla* sp.) fattening in the
824 Southwest part of Bangladesh. *Marine Res Aqua* 1:5–13.

825 Ferdoushi Z, Xiang-Guo Z (2013) An assessment on the barriers in mud crab (*Scylla* sp.)
826 fattening and marketing in Bangladesh. *J Sci Technol (Dinajpur)* 11:151–157.

827 Ferdoushi Z, Xiang-Guo Z, Hasan MR (2010) Mud crab (*Scylla* sp.) marketing system in
828 Bangladesh. *As J Food Ag-Ind* 3:248–265.

829 Fielder DS, Mann DL, Heasman MP (1988) Development of intensive pond farming
830 techniques for mud crab *Scylla serrata* (Forsk.) in Northern Australia. FIRTA Project
831 Report 86/9. 37 pp.

832 Fortes RD (1999) Mud crab research and development in the Philippines: an overview. In:
833 Keenan, C.P., Blackshaw, A. (Eds.), *Mud crab aquaculture and biology*, Proceedings
834 of the ACIAR, Australia, 78, 27–32.

835 FRSS (2017) Yearbook of fisheries statistics of Bangladesh 2016-17. Department of
836 Fisheries, Dhaka, Bangladesh.

837 Gaillard J (2010) Development of the mud crab sector in three provinces of the Philippines -
838 constraints and prospects. *AgroCampus Ouest*. [https://halieutique.agrocampus-](https://halieutique.agrocampus-ouest.fr/memoires/201006.pdf)
839 [ouest.fr/memoires/201006.pdf](https://halieutique.agrocampus-ouest.fr/memoires/201006.pdf)

840 Garza-Gil MD, Varela-Lafuente M, Caballero-Miguez G (2009) Price and production trends
841 in the marine fish aquaculture in Spain. *Aquac Res* 40:274–281.
842 <https://doi.org/10.1111/j.1365-2109.2008.02106.x>

843 Genodepa JG (1999) Pen culture experiments of the mud crab *Scylla serrata* in mangrove
844 areas. In: Keenan CP, Blackshaw A (Eds.), *Mud crab aquaculture and biology*,
845 Proceedings of the ACIAR, Australia, 78:89–94.

846 Germain N, Hartmann HJ, Melo FJF, Reyes-Bonilla H (2015) Ornamental reef fish fisheries:
847 New indicators of sustainability and human development at a coastal community

848 level. *Ocean Coast Manag* 104:136–149.
849 <https://doi.org/10.1016/j.ocecoaman.2014.12.007>

850 Ghazali A, Azra MN, Noordin NM, Abol-Munafi AB, Ikhwanuddin M (2017) Ovarian
851 morphological development and fatty acids profile of mud crab (*Scylla olivacea*) fed
852 with various diets. *Aquaculture* 468:45–52.
853 <https://doi.org/10.1016/j.aquaculture.2016.09.038>

854 Gokoolu N, Yerlikaya P (2003) Determination of proximate composition and mineral contents
855 of blue crab (*Callinectes sapidus*) and swim crab (*Portunus pelagicus*) caught off the
856 Gulf of Antalya *Food Chem* 80:495–498. [https://doi.org/10.1016/S0308-](https://doi.org/10.1016/S0308-8146(02)00318-7)
857 [8146\(02\)00318-7](https://doi.org/10.1016/S0308-8146(02)00318-7)

858 Helms MM, Nixon J (2010) Exploring SWOT analysis. Where are we now? A review of
859 academic research from the last decade. *Journal of Strategy and Management*
860 3:215–251.

861 Hoegh-Guldberg O, Bruno JF (2010) The impact of climate change on the world's marine
862 ecosystems. *Science* 328:1523–1528. <https://doi.org/10.1126/science.1189930>

863 Hoq ME (2007) An analysis of fisheries exploitation and management practices in
864 Sundarbans mangrove ecosystem, Bangladesh. *Ocean Coast Manag* 50:411–427.
865 <https://doi.org/10.1016/j.ocecoaman.2006.11.001>

866 Hoque SF, Quinn C, Sallu S (2018) Differential livelihood adaptation to social-ecological
867 change in coastal Bangladesh. *Reg Environ Change* 18:451–463.
868 <https://doi.org/10.1007/s10113-017-1213-6>

869 Hungria DB, Tavares CPDS, Pereira LÂ, Silva UDATD, Ostrensky A (2017) Global status of
870 production and commercialization of soft-shell crabs. *Aquac Int* 25:2213–2226.
871 <https://doi.org/10.1007/s10499-017-0183-5>

872 Huq N, Hugé J, Boon E, Gain AK (2015) Climate change impacts in agricultural communities
873 in rural areas of coastal Bangladesh: a tale of many stories. *Sustainability* 7:8437–
874 8460; <https://doi.org/10.3390/su7078437>

875 Hussain MG, Failler P, Al Karim A, Alam MK (2018) Major opportunities of blue economy
876 development in Bangladesh. *Journal of the Indian Ocean Region* 14:88–99.
877 <https://doi.org/10.1080/19480881.2017.1368250>

878 Ikhwanuddin M, Mansor JH, Bolong AMA, Long SM (2012) Improved hatchery-rearing
879 techniques for juvenile production of blue swimming crab, *Portunus pelagicus*

880 (Linnaeus, 1758). Aquac Res 43:1251–1259. <https://doi.org/10.1111/j.1365->
881 2109.2011.2929.x

882 IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability: summary for
883 policymakers. Working Group II Contribution to the Intergovernmental Panel on
884 Climate Change Fourth Assessment Report. IPCC, Geneva.

885 Islam MR, Hoque MN, Galib SM, Rahman MA (2013) Livelihood of the fishermen in
886 Monirampur Upazila of Jessore district, Bangladesh. J Fish 1:37–41.

887 Islam MS, Aleem NA, Rahman MM (2015) Mud crab aquaculture, present status, prospect
888 and sustainability in Bangladesh. World Aquaculture 46:58–60.

889 Islam SMD, Bhuiyan MAH (2016) Impact scenarios of shrimp farming in coastal region of
890 Bangladesh: an approach of an ecological model for sustainable management.
891 Aquacult Int 24:1163–1190. <https://doi.org/10.1007/s10499-016-9978-z>

892 Istiak SM (2018) Study for assessing mud crab (*Scylla serrata*, Forskal, 1755) market chain
893 and value-added products development in Bangladesh. Bangladesh J Zool 46:263–
894 273.

895 Johnson G, Scholes K (1997) Exploring corporate strategic, 4th ed. Prentice Hall, London.

896 Johnson G, Scholes K, Sixty RW (1989) Exploring strategic management. Prentice Hall,
897 Scarborough, Ontario, Canada.

898 Johnston D, Harris D, Caputi N, Thomson A (2011) Decline of a blue swimmer crab
899 (*Portunus pelagicus*) fishery in Western Australia—history, contributing factors and
900 future management strategy. Fish Res 109:119–130.
901 <https://doi.org/10.1016/j.fishres.2011.01.027>

902 Johnston D, Keenan CP (1999) Mud crab culture in the Minh Hai Province, South Vietnam.
903 In: Keenan CP, Blackshaw A (Eds.) Mud crab aquaculture and biology, Proceedings
904 of the ACIAR, Australia, 78:95–98.

905 Jurevicius O (2013) SWOT analysis- do it properly! Strategic Management Insight.
906 <https://www.strategicmanagementinsight.com/tools/swot-analysis-how-to-do-it.html>
907 (Accessed 17 January 2018)

908 Karim M, Stellwagen J (1998) Final report on fourth fisheries project: Shrimp aquaculture
909 (Preparatory Phase for National Development Programme). Department of Fisheries,
910 Ministry of Fisheries and Livestock, Bangladesh.

911 Karthik M, Suri J, Saharan N, Biradar RS (2005) Brackish water aquaculture site selection in
912 Palghar Taluk, Thane district of Maharashtra, India, using the techniques of remote

913 sensing and geographical information system. *Aquacultural Engineering* 32:285–302.
 914 <https://doi.org/10.1016/j.aquaeng.2004.05.009>

915 Kasprzyk Z, Rajaonson C (2013) Handling of mud crab: illustrated operators' manual. FAO
 916 Smart Fish Publication No. 11. Mauritius, Indian Ocean Commission & FAO.

917 Keenan CP, Davie PJF, Mann DL (1998) A revision of the genus *Scylla* de Hann, 1833
 918 (Crustacea: Decapoda: Brachyura: Portunidae). *Raffles Bull Zool* 46:217–245.

919 Khatun M, Kamal D, Ikejima K, Yi Y (2009) Comparisons of growth and economic
 920 performance among monosex and mixed-sex culture of red mud crab (*Scylla olivacea*
 921 Herbst, 1796) in bamboo pens in the tidal flats of mangrove forests, Bangladesh.
 922 *Aquac Res* 40:473–485. <https://doi.org/10.1111/j.1365-2109.2008.02119.x>

923 Kosuge T (2001) Brief assessment of stock of mud crabs *Scylla* sp. in Matang Mangrove
 924 Forest, Malaysia and proposal for resources management. *Jpn Agric Res Q*, 35, 145–
 925 148.

926 Kumar J (2015) MPEDA's Maharashtra crab farming project a
 927 success.[http://www.thefishsite.com/fishnews/25644/mpedas-maharashtra-crab-](http://www.thefishsite.com/fishnews/25644/mpedas-maharashtra-crab-farming-project-a-success/)
 928 [farming-project-a-success/](http://www.thefishsite.com/fishnews/25644/mpedas-maharashtra-crab-farming-project-a-success/). (Accessed 17 January 2019)

929 Le Vay L (2001) Ecology and management of mud crabs, *Scylla* spp. *Asian Fish Sci* 14:101–
 930 111.

931 Liong PC (1991) The fattening and culture of the mud crab (*Scylla serrata*) in Malaysia, in:
 932 Angell CA (Eds.) Report of the seminar on the mud crab culture and trade, 5–8
 933 November 1991, Surat Thani, Thailand, pp. 185–190.

934 Macintosh DJ, Overton JL, Thu HVT (2002) Confirmation of two common mud crab species
 935 (genus *Scylla*) in the mangrove ecosystem of the Mekong Delta, Vietnam. *J Shellfish*
 936 *Res* 21:259–265.

937 Mahmud A (2017) Crab export is at stake. Kalerkantha, Dhaka, Bangladesh. Accessed on
 938 19 Jan 2019. [http://www.kalerkantho.com/print-edition/industry-](http://www.kalerkantho.com/print-edition/industry-business/2017/01/01/447451)
 939 [business/2017/01/01/447451](http://www.kalerkantho.com/print-edition/industry-business/2017/01/01/447451)

940 Mahmud AI, Mamun AA (2012) Feasibility study on the culture of mud crab *Scylla serrata* in
 941 the mid-coast region of Bangladesh. *Pakistan J Biol Sci* 15:1191–1195.

942 Mahmuduzzaman M, Ahmed ZU, Nuruzzaman AKM, Fazle Rabbi Sadeque Ahmed (2014)
 943 Causes of salinity intrusion in coastal belt of Bangladesh. *International Journal of*
 944 *Plant Research* 4:8–13. <https://doi.org/10.5923/s.plant.201401.02>

945 Mamun-ur-Rashid M, Kamruzzaman M, Mustafa E (2017) Women participation in
 946 agricultural extension services in Bangladesh: current status, prospects and
 947 challenges. Bangladesh J Ext Edu 29:93–107.

948 Marichamy R, Rajapackiam S (1999) Commercial farming of mud crab in coastal ponds at
 949 Tuticorin. Proceedings of the Fourth Indian Fisheries Forum. Asian Fisheries Society,
 950 pp. 215–218.

951 Marichamy R, Rajapackiam S (2001) The aquaculture of *Scylla* species in India. Asian Fish
 952 Sci 14:231–238

953 Mirera DO, Mtile A (2009) A preliminary study on the response of mangrove mud crab
 954 (*Scylla serrata*) to different feed types under drive in cage culture system. J Ecol Nat
 955 Environ 1:7–14.

956 Molla MAG, Islam MR, Islam S, Salam MA (2009) Socio-economic status of crab collectors
 957 and fatteners in the southwest region of Bangladesh. J Bangladesh Agril Univ 7:411–
 958 419.

959 Mollenhorst H, de Boer IJM (2004) Identifying sustainability issues using participatory SWOT
 960 analysis—a case study of egg production in the Netherlands. Outlook Agric 33:267–
 961 276. <https://doi.org/10.5367%2F0000000042664747>

962 Noorbaiduri S, Abol-Munafi AB, Ikhwanuddin M (2014) Acrosome rejection stage of sperm
 963 for mud crab, *Scylla olivacea* (Herbst, 1796): mating in wild and in captivity. J Fish
 964 Aquat Sci 9:237–244.

965 Noorbaiduri S, Ikhwanuddin M (2015) Artificial crablets production of orange mud crab,
 966 *Scylla olivacea* (Herbst, 1796) through *in-vitro* fertilization technique. J Fish Aquat Sci
 967 10:102–110.

968 Nouri J, Karbassi AR, Mirkia S (2008) Environmental management of coastal regions in the
 969 Caspian Sea. Int J Environ Sci Technol (Tehran) 5:43–52.

970 NRI Report (2003) Livelihoods in coastal fishing communities, and the marine fish marketing
 971 system of Bangladesh. Report No. 2712, Project A1004, U.K. Natural Resources
 972 Institute, pp. 67–73.

973 Ommani AR (2011) Strengths, weaknesses, opportunities and threats (SWOT) analysis for
 974 farming system businesses management: case of wheat farmers of Shadervan
 975 District, Shoushtar Township, Iran. Afr J Bus Manage 5:9448–9454.

976 Overton JL, Macintosh DJ (1997) Mud crab culture: prospects for the small-scale Asian
 977 farmer. Infofish International 5:26–32.

978 Panigrahi JK, Mohanty PK (2012) Effectiveness of the Indian coastal regulation zones
 979 provisions for coastal zone management and its evaluation using SWOT analysis.
 980 Ocean Coast Manag 65:34–50. <https://doi.org/10.1016/j.ocecoaman.2012.04.023>

981 Paul BG, Vogl CR (2011) Impacts of shrimp farming in Bangladesh: challenges and
 982 alternatives. Ocean Coast Manag 54:201–211.
 983 <https://doi.org/10.1016/j.ocecoaman.2010.12.001>

984 Paul SK, Routray JK (2011) Household response to cyclone induced surge in coastal
 985 Bangladesh: coping strategies and explanatory variables. Nat Hazards 57:477–499.
 986 <https://doi.org/10.1007/s11069-010-9631-5>

987 Pollnac RB, Weeks P (1992) Coastal aquaculture in developing countries: problems and
 988 perspectives. International Center for Marine Resource Development, University of
 989 Rhode Island, USA.

990 Pripanapong S, Tongdee NA (1998) Review of the mud crab (*Scylla sp.*) fisheries and
 991 culture in Thailand. Newsletter of Danish-SE Asian Collaboration in Tropical Coastal
 992 Ecosystems Research and Training Project, Denmark, Thailand and Malaysia, 2(2),
 993 7–10

994 Quintio ET (2015) Status of mud crab industry in the Philippines. In Quintio ET, Parado-
 995 Estepa FD, Thampi Sam Raj YC, Mandal A (Eds), Proceedings of the International
 996 Seminar-Workshop on Mud Crab Aquaculture and Fisheries Management, 10–12
 997 April 2013, Tamil Nadu, India (pp. 27–35). Tamil Nadu, India: Rajiv Gandhi Centre for
 998 Aquaculture (MPEDA).

999 Rachel M (2002) Gender, development, and climate change. Oxfam Great Britain, Oxford,
 1000 United Kingdom.

1001 Rahman MM, Haque SM, Wahab A, Eгна H, Brown C (2018) Soft-shell crab production in
 1002 coastal Bangladesh: prospects, challenges and sustainability. World Aquaculture
 1003 49:43–47.

1004 Rahman MM, Islam MA, Haque SM, Wahab A (2017) Mud crab aquaculture and fisheries in
 1005 coastal Bangladesh. World Aquaculture 48:47–52.

1006 Rimmer MA, Sugama K, Rakhmawati D, Rofiq R, Hapbood RH (2013) A review and SWOT
 1007 analysis of aquaculture development in Indonesia. Rev Aquacult 5:255–279.
 1008 <https://doi.org/10.1111/raq.12017>

1009 Rosenberry B (2012) Mitten crab farming in China. From “Aquaculture: Farming Aquatic
 1010 Animals and Plants”.

1011 [http://www.shrimpnews.com/FreeReportsFolder/CrabFolder/MittenCrabFarmingInChi](http://www.shrimpnews.com/FreeReportsFolder/CrabFolder/MittenCrabFarmingInChina.html)
1012 [na.html](http://www.shrimpnews.com/FreeReportsFolder/CrabFolder/MittenCrabFarmingInChina.html). (Accessed 17 January 2019)

1013 Roy BJ, Nripendra KS, Hasan Ali, SM, Rahman MG (2013) Exploitation of marine swimming
1014 crabs as by-catch in artisanal fishery of the Bay of Bengal. *Glo Adv Res J Agric Sci*
1015 2:283–288.

1016 Saha MR, Rahman MM, Ahmed SU, Rahman S, Pal HK (2000) Study on the effect of
1017 stocking density on brood stock development of mud crab *Scylla serrata* in brackish
1018 water earthen ponds. *Pakistan J Biol Sci* 3:389–391.
1019 <http://dx.doi.org/10.3923/pjbs.2000.389.391>

1020 Salam MA, Hossain MS, Tareque AMHB (2005) Studies on the present status and future
1021 potential of molluscs, dry fish and crab in Bangladesh coast: a GIS methodological
1022 perspective. *Value Chain and Market Assessment of Coastal and Marine Aquatic*
1023 *Products of Bangladesh*, Bangladesh Fisheries Research Forum, Dhaka,
1024 Bangladesh, pp. 192–210.

1025 Salam MA, Ross LG (2000) Optimizing site selection for development of shrimp (*Penaeus*
1026 *monodon*) and mud crab (*Scylla serrata*) culture in South-western Bangladesh, in:
1027 14th Annual Conference on Geographic Information Systems, Proceedings of the
1028 GIS. Toronto, Canada.

1029 Salam MA, Ross LG, Beveridge CMM (2003) A comparison of development opportunities for
1030 crab and shrimp aquaculture in southwestern Bangladesh, using GIS modelling.
1031 *Aquaculture*, 220:477–494. [https://doi.org/10.1016/S0044-8486\(02\)00619-1](https://doi.org/10.1016/S0044-8486(02)00619-1)

1032 Sathiadhas R, Najmudeen TM (2004) Economic evaluation of mud crab farming under
1033 different production systems in India. *Aquaculture Economics & Management* 8:99–
1034 110.

1035 Shafi M, Quddus MMA (1982) *Fisheries Resources of Bangladesh*. Bangla Academy,
1036 Dhaka, Bangladesh.

1037 Shelley C (2008) Capture-based aquaculture of mud crabs (*Scylla* spp.) Global Overview
1038 *FAO Fisheries Technical Paper* 5008:15

1039 Shelley C (2013) Scoping study for mud crab farming in Bangladesh-Part 2.C.C. Shelley Pty
1040 Ltd. March 2013.[pubs.iclarm.net/resource_centre/Final-Report-Mud-Crab-](http://pubs.iclarm.net/resource_centre/Final-Report-Mud-Crab-Bangladesh-March-2013.pdf)
1041 [Bangladesh-March-2013.pdf](http://pubs.iclarm.net/resource_centre/Final-Report-Mud-Crab-Bangladesh-March-2013.pdf) (Accessed 21 January 2019).

1042 Shelley C, Lovatelli A (2011) Mud crab aquaculture. In: *A practical manual*. *Aquaculture*
1043 *Technical Paper* (FAO), FAO fisheries and aquaculture technical paper 567, Rome.

1044 Stead SM (2005) Changes in Scottish coastal fishing communities- understanding socio-
 1045 economic dynamics to aid management, planning and policy. *Ocean Coast Manag*
 1046 48:670–692. <https://doi.org/10.1016/j.ocecoaman.2005.08.001>

1047 Sulaeman TM, Hanafi A (1993) Grow-out of the mangrove crab *Scylla serrata* in ponds of
 1048 different types of construction. *Research Journal on Coastal Aquaculture*, 9, 41–50.

1049 Tobey J, Torell E (2006) Coastal poverty and MPA management in mainland Tanzania and
 1050 Zanzibar. *Ocean Coast Manag* 49:834-854.
 1051 <https://doi.org/10.1016/j.ocecoaman.2006.08.002>

1052 Toufique KA, Yunus M (2013) Vulnerability of livelihoods in the coastal districts of
 1053 Bangladesh. *Bangladesh Development Studies* XXXVI:95–120.

1054 UNDP (2010) Human Development Report 2010. 20th Anniversary Edition. The United
 1055 Nations Development Programme. New York, USA.

1056 UNEP (2014) The UNEP Environmental Data Explorer, as compiled from
 1057 UNEP/DEWA/GRID-Geneva. United Nations Environment Programme, Geneva.
 1058 <http://geodata.grid.unep.ch>.

1059 Walton MEM, Le Vay L, Lebata JH, Binas J, Primavera JH (2006) Seasonal abundance,
 1060 distribution and recruitment of mud crabs (*Scylla* spp.) in replanted mangroves. *Est*
 1061 *Coast Shelf Sci* 66:493–500. <https://doi.org/10.1016/j.ecss.2005.09.015>

1062 Wickins JF, Lee DOC (2002) Crustacean farming ranching and culture, Second edition.
 1063 Blackwell Science, Oxford, England.

1064 Zafar M, Ahsan MN (2006) Marketing and value chain analysis of mud crab (*Scylla* sp.) in
 1065 the coastal communities of Bangladesh. In: Islam MA, Ahmed K, Akhteruzzaman M,
 1066 (Eds) Value chain and market assessment of coastal and marine aquatic products of
 1067 Bangladesh, BFRF/AFGRP/DFID, pp. 25–53.

1068 Zafar M, Siddiqui MZH, Houqe MA (2004) Biochemical composition in *Scylla serrata*
 1069 (Forsk.) of Chakaria Sundarban Area, Bangladesh. *Pakistan J Biol Sci* 7:2182–2186.
 1070 <http://dx.doi.org/10.3923/pjbs.2004.2182.2186>

1071 Zaitsev V, Kizevete I, Lagunoy L, Makarov T (1969) Fish curing and processing. Mir
 1072 publishers, Moscow.

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1074

1075 **Table 1:** Personal and housing data of mud crab collectors and farmers obtained through
1076 socio-economic surveys

<i>Household attributes</i>		<i>Percentage (%)</i>	
		<i>Crab collectors (N = 75)</i>	<i>Crab farmers (N = 150)</i>
Sex	Men	74.7	69.3
	Women	25.3	30.7
Civil status	Married	77.3	80.0
	Single	14.7	11.3
	Widowed	5.3	4.7
	Divorced/abandoned	2.7	4.0
Religion	Hindus	78.7	64.0
	Muslim	20.0	34.0
	Christian	1.3	2.0
Age	< 20 years	6.7	0.0
	20 – 30 years	26.7	19.3
	30 – 40 years	44.0	56.7
	40 – 50 years	17.3	18.0
	> 50 years	5.3	6.0
Schooling	No schooling	17.3	4.0
	Primary school	52.0	33.3
	Secondary school	24.0	41.3
	Higher secondary and above	6.7	21.3
Other economic activities	Yes	65	58.7
	No	35	41.3
Father involved in crab collection/culture	Yes	57	18
	No	33	82
Land holding ^a	1–50 decimal	36.0	16.7
	50–100 decimal	45.3	47.3
	100–150 decimal	16.0	32.0
	>150 decimal	2.7	4.0
Annual income ^b	<50000 BDT	0.0	0.0
	50000 – 100000 BDT	24.0	14.7
	100000 – 150000 BDT	45.3	41.3
	150000 – 200000 BDT	18.7	30.7
	>200000 BDT	12.0	13.3
Access to credit facilities	Relatives	6.7	9.3
	Money lender	8.0	3.3
	NGOs	36.0	40.0
	Banks	0.0	7.3
	Crab depots holders, <i>Farias</i>	49.3	40.0
Health	Diseases		
	Gastritis (Stomach)	74.7	26.0
	Respiratory	41.3	15.3

	High blood pressure	17.3	23.3
	Diabetics	8.0	12.7
	Backache	36.0	27.3
	None	16.0	14.0
	Treatment		
	Village doctor	63	37
	Upazila Health Complex	33	51
	Private clinic	4	12
Experience with crab activities	Ave. experience (years)	16.4	5.1
	Highest experience	34.7	14.0
	Lowest experience	6.7	1.3
Housing conditions ^c	Kacha	16	08
	Tin shaded	39	16
	Semi-pucca	32	54
	Pucca	13	22
Household facilities	Use of electronics		
	Cell phone	72	86
	Television	21	50
	Refrigerator	00	2.67
	Type of sanitary facilities^d		
	Pucca	13	22
	Semi-pucca	52	62
	Kacha	35	16
	Power sources		
	Electricity	29	58
	Solar	47	26
	Wood / fuel	24	16
	Transport		
	None	81	58
	Motor cycle	4	22
	Rickshaw	15	20

1077 ^a, 1 ha = 247 decimal;

1078 ^b, 1 US\$ = ~80 BDT;

1079 ^c, Housing conditions: kacha, wall made of mud/bamboo splits with golpata [leaves of *Nypa*
1080 spp., collected from the Sundarbans] shed or thatched; tin shaded, wall made of bamboo
1081 splits with tin shed; semi-pucca, concrete-based wall made of tin with tin shed; and pucca,
1082 concrete wall with tin shaded roof/concrete roof.

1083 ^d, Sanitary facilities: pucca, concrete wall with tin shaded roof/concrete roof; semi-pucca,
1084 crushed bamboo mat (locally called *chata*) or tin walled with ring slave; and kacha, wall
1085 covered with sackcloth or polythene (locally called *chat/sala*) and having no shed.

1086

Table 2: Different HDI indices of the wild mud crab collectors and farmers of southwest Bangladesh.

<i>Indices</i>	<i>Crab collectors</i>	<i>Crab farmers</i>
Economic index	0.58	0.49
Schooling index	0.32	0.44
Life expectancy index	0.8	0.8
HDIMCF	0.64	0.61

Table 3. Evaluation of internal factors (EIF) of mud crab fishery in Bangladesh

Sl.	Internal Factors	Weight	Rate	Score
Strengths				
S ₁	Availability of commercially important mud crabs species locally	0.08	4	0.32
S ₂	High demand and price in local and export markets	0.09	4	0.36
S ₃	Ranked very high among exportable aquatic species	0.03	3	0.09
S ₄	High tolerance to environmental factors and diseases	0.07	4	0.28
S ₅	Gaining popularity among coastal communities	0.03	3	0.09
S ₆	Simple dietary requirements (e.g. easily fed with low valued fish)	0.04	3	0.12
S ₇	Year-round production in all types of ponds	0.05	4	0.2
S ₈	Diversified culture systems (e.g. fattening, grow-out, soft-shell farming, polyculture)	0.05	4	0.2
S ₉	Alternative income and livelihood options to vulnerable coastal communities	0.05	4	0.2
Weaknesses				
W ₁	Complete dependency on wild stocks	0.09	1	0.09
W ₂	Traditional or extensive farming systems	0.02	2	0.04
W ₃	Lack of technical expertise, trainings, and extension services	0.06	1	0.06
W ₄	Lack of capital of farmers and limited access to financial supports	0.03	2	0.06
W ₅	Limited domestic consumption	0.03	2	0.06
W ₆	Lack of standard marketing facilities	0.04	2	0.08
W ₇	Poor population data of existing stock in the wild (population status, breeding season, breeding and nursery grounds and so on)	0.08	2	0.16
W ₈	Poor post-catch handling with poor storage facilities and transportation system causes high mortality	0.04	2	0.08
W ₉	Inadequate data on production, marketing and export	0.04	2	0.08
W ₁₀	Lack of appropriate and sustainable policies, and coordination among relevant government agencies, and stakeholders	0.08	1	0.08
Sum		1		2.65

S: strength; W: weakness

1094 **Table 4.** Evaluation of external factors (EEF) of mud crab fishery in Bangladesh

<i>External factors</i>	<i>Weight</i>	<i>Rate</i>	<i>Score</i>
Opportunities			
O ₁ Suitable water bodies for crab aquaculture	0.1	4	0.4
O ₂ Potential coastal farmers	0.05	3	0.15
O ₃ Potential export markets	0.04	3	0.12
O ₄ Improved technology and best management practices	0.05	3	0.15
O ₅ Access to modern post-harvest facilities will reduce mortality and production loss	0.09	3	0.27
O ₆ Successful hatchery technology will certainly boost the fishery	0.1	4	0.4
O ₇ Potential for value additions and product promotion	0.05	3	0.15
O ₈ Enterprise and industrial development	0.08	3	0.24
O ₉ Promulgation of domestic consumption	0.02	3	0.06
O ₁₀ Appropriate policies and initiatives can help the fishery become more economically functional	0.06	4	0.24
O ₁₁ Awareness building and law enforcement can support to exploit the fishery sustainably	0.05	3	0.15
T ₁ Exports solely based on harvesting of wild stocks	0.1	1	0.1
T ₂ Excessive and indiscriminate harvesting of wild population	0.1	1	0.1
T ₃ Uncertain market in some cases	0.06	2	0.12
T ₄ Disease outbreak	0.05	1	0.05
Sum	1		2.7

O: opportunity; T: threat

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Figure captions

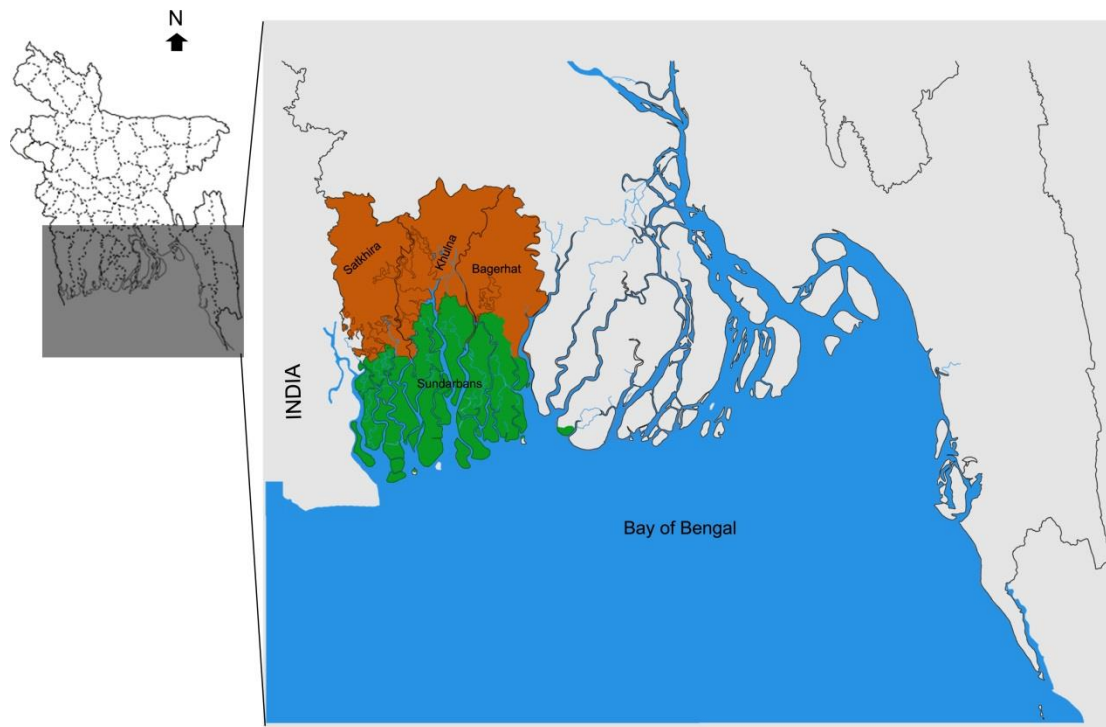


Fig. 1. Coastal regions of Bangladesh showing the study areas (Satkhira, Khulna and Bagerhat districts) featuring the Sundarbans mangrove forest.

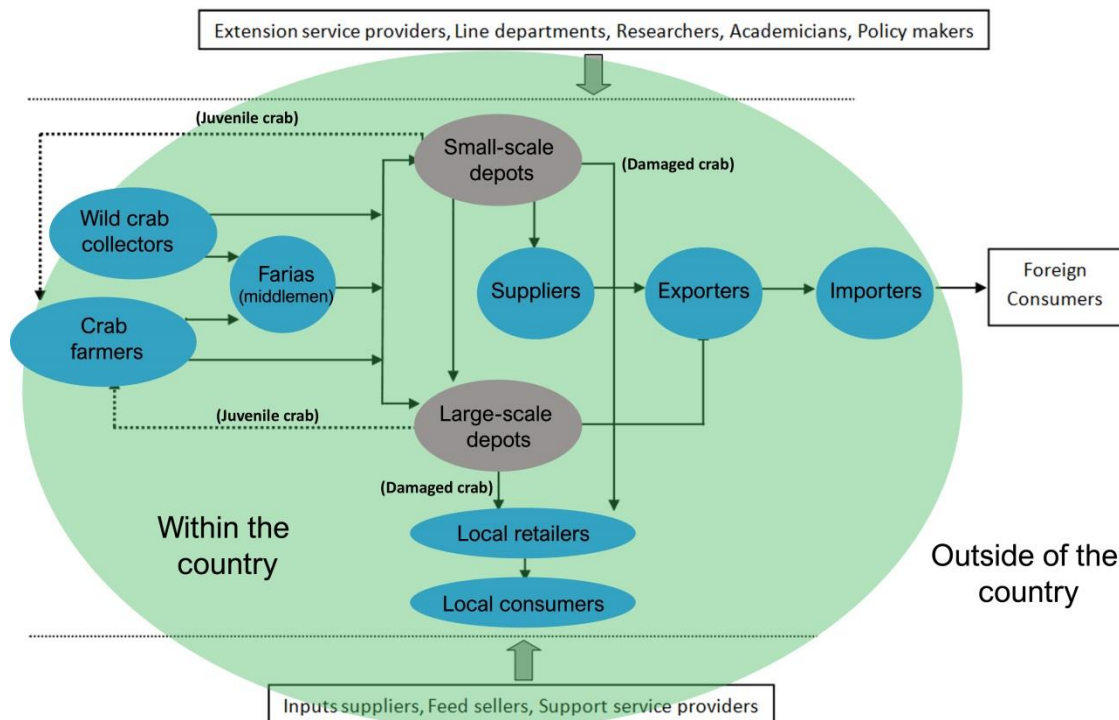
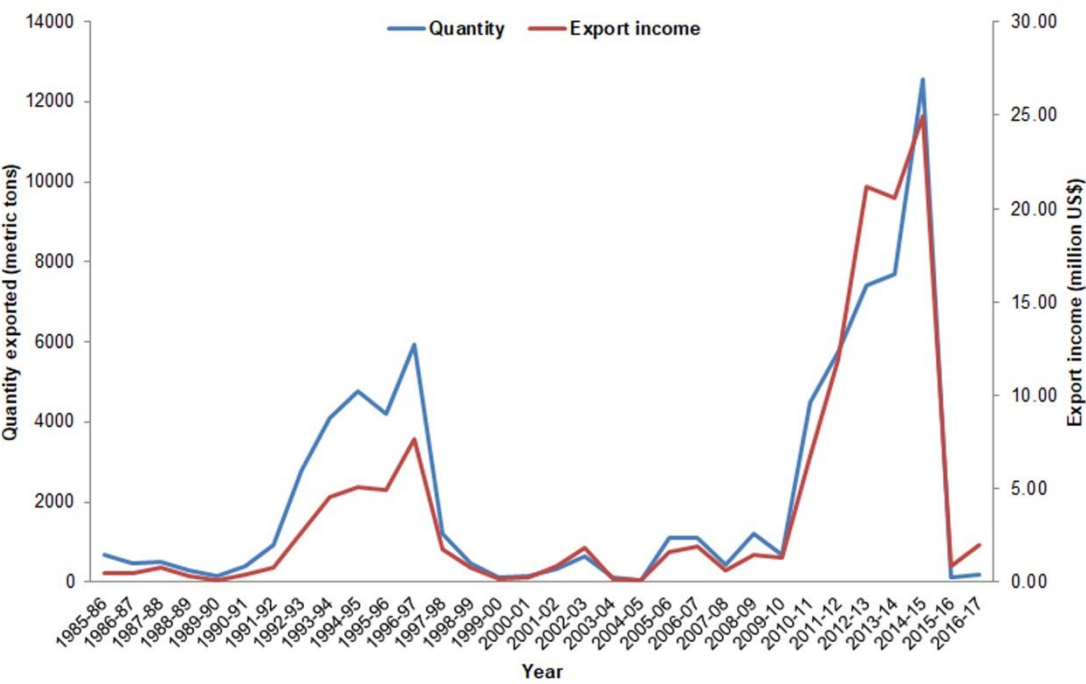


Fig. 2. Stakeholders of a typical mud crab value chain in southwest coastal Bangladesh

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1107 **Fig. 3:** Status of mud crab export from Bangladesh (source: FRSS 2017)

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